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Average Annual Sediment Yields in Minnesota

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Average Annual Sediment Yields in Minnesota

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Introduction

With the current emphasis on nonpoint pollution, not only must the quantity of soil being eroded from upland areas be known but also the amount of upland sediment entering stream systems and the amount actually leaving the watershed. Identifying the actual sediment source areas also is important. Models are presently being developed that route sediment from upland sources through watersheds, but these models generally need to be calibrated to watershed yield (7, 11).³ In this paper, we analyzed data from 23 Minnesota watersheds to obtain estimates of such yields, to classify areas of Minnesota by general sediment-yield categories, and to estimate monthly distribution of sediment yields.

Sediment-Yield Analysis

Average annual suspended sediment yield was estimated by the flow duration-sediment rating curve (9). Although specific source areas within a watershed are not identified, we selected the method because data at river-gaging stations were available. The U.S. Department of Interior, Geological Survey (USGS), has collected discharge and suspended sediment data at various stations throughout Minnesota since 1967 (10). Few data were available, however, on sediment loads in Minnesota streams before 1967 (2).

We selected 23 river stations throughout Minnesota as having enough data to estimate, reasonably, average annual yields. The number of sediment samples taken from each station (table 1) ranged from 90, from the Whitewater River near Elba, to 2,923, from the Minnesota River at Mankato. Samples were collected with standard US DH-48, US DH-59, or US D-49 depth-integrating samplers (2).

Sediment concentrations and the corresponding discharges were used to derive sediment-rating curves for each of the stations. These data were plotted and analyzed using a first, second, third, and fourth degree polynomial regression. Equation [1] represents the general form of the sediment-rating curves:

$$\text{LOG(YIELD)} = A + B1[\text{LOG (DISCH)}] + B2[\text{LOG (DISCH)}]^2 + B3[\text{LOG (DISCH)}]^3 + B4[\text{LOG (DISCH)}]^4 \quad [1]$$

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³ Italic numbers in parentheses refer to Literature Cited page 9.

TABLE 1.—Sediment-rating curve summary

	Number of sediment samples	Polynomial coefficients ¹						R ²
		A	B1	B2	B3	B4		
1. Baptism River, Beaver Bay	243	—0.476	0.768	0.066	0.207	0.181	0.74	
2. Pelican River, Fergus Falls	191	.081	1.103	— .229	.193	.181	.55	
3. Buffalo River, Dilworth	339	.826	.912				.60	
4. Wild Rice River, Twin Valley	338	.118	1.695				.65	
5. Middle River, Argyle	308	.411	1.156	— .045	— .015	.054	.95	
6. Little Fork River, Little Fork	369	—1.049	1.916				.73	
7. Crow Wing River, Nimrod	418	— .934	1.672				.53	
8. Yellow Bank River, Odessa	730	.655	1.024	.381	.140		.89	
9. Chippewa River, Milan	188	.661	1.025	3.283	—4.244	1.373	.61	
10. Redwood River, Marshall	264	1.006	1.582				.93	
11. Redwood River, Redwood Falls	205	.984	1.194				.87	
12. Cottonwood River, New Ulm	927	.791	1.383				.87	
13. Minnesota River, Mankato	2,923	.325	1.427				.67	
14. Zumbro River, Zumbro Falls	314	1.001	—1.829	2.559	— .519		.80	
15. Root River, Lanesboro	91	.593	—2.925	9.813	—6.364	1.302	.50	
16. Root River, Houston	767	— .196	2.046				.60	
17. Cedar River, Austin	171	— .188	2.60	—1.291	.438		.56	
18. W. Fork, Des Moines, River, Jackson	700	.720	1.215	— .053	— .030	.021	.78	
19. Whetstone River, Big Stone City S.D.	730	.546	1.030	.428	.124	— .082	.87	
20. St. Louis River, Forbes	350	— .500	1.120	.188	.044		.81	
21. Straight River, Faribault	359	.195	1.790				.68	
22. N. Fork, Whitewater River, Elba ...	90	.640	2.222				.85	
23. Minnesota River, New Ulm	2,922	.868	1.073				.67	

¹ Equation [1]: $\text{LOG(YIELD)} = A + B1[\text{LOG(DISCH)}] + B2[\text{LOG(DISCH)}]^2 + B3[\text{LOG(DISCH)}]^3 + B4[\text{LOG(DISCH)}]^4$

where

$\text{YIELD} = \text{sediment yield of the recording station in metric tons per day}$

and

$\text{DISCH} = \text{river discharge at the recording station in cubic meters per second.}$

The regression equation used to represent the relation between the suspended sediment load and discharge (table 1) was selected based on the coefficient of determination (R^2), the number of data points, and the range of the sediment loads represented by the data points. Linear estimators generally were used unless sufficient data were available, illustrating a clear trend other than linear. The R^2 values ranged from 0.50 to 0.95 and averaged 0.73.

Flow-duration data have been collected by the USGS for up to 35 years at various stations throughout Minnesota (4). The lengths of records (table 2) indicate that the flow-duration data are more reliable than the sediment data.

With the flow-duration and sediment-rating curves defined, average annual sediment yields were estimated. The flow-duration curves defined the average percentage of time that the discharge for a given stream was between certain limits. The sediment-rating curve is used to estimate the average sediment concentration between the same discharge limits. By summing the products of the fraction of time that the river was at a given discharge and the load carried at that discharge, over the range of the discharges, we estimated average annual sediment yield (table 2). The estimated average annual sediment yield does not include bed load. The yields vary from a low of 10 kg/ha/yr to a high of 1,084 kg/ha/yr. The size of the drainage areas ranged from 262 km² to 38,600 km².

Concentration values are also presented in table 2. Estimates of average concentrations ranged from 9 to 622 mg/l. The concentrations tended to increase as the sediment yields increased, but the trend was quite erratic, as was shown by the Cedar River and the West Fork of the Des Moines River. The maximum of the average monthly concentrations were typically from two to five times the average annual concentrations.

Sediment-Yield Results

The average annual sediment yields were used to prepare a statewide map (fig. 1) showing areas of relative sediment yield. To complete the map, we used basins from which predicted data were available as references and inferred the sediment yields of adjacent areas by comparing such basin characteristics as soils (1, 3), land use (5), and basin size. Another aid in extending the data was the Reconnaissance Erosion Survey of the State of Minnesota (8), which indicated the types and location of erosion, based on a county survey.

The map produced is quite general, indicating the differences only between large areas of the State. Local variation within a given area may be considerable. Also, the sediment yields, as well as the concentration values, are average annual values. Values for a given year may vary considerably.

In general, the basins in the forest regions of the central and northern portion of the State had a low sediment yield, except for the Little Fork and St. Louis basins.

TABLE 2.—Summary of flow duration and suspended sediment data

	Drainage area km ²	Years of flow- duration data	Years of sediment- concentration data	Predicted		Maximum of average monthly concentrations ⁴ mg/l
				average annual sediment yield kg/ha	Predicted average annual concentration mg/l	
1. Baptism River near Beaver Bay	362	1931-68	1968-70	42	11	—
2. Pelican River near Fergus Falls ¹	1,250	² 1943-68	1968-70	10	16	—
3. Buffalo River near Dilworth	2,700	² 1931-60	² 1973-75	25	63	—
4. Wild Rice River at Twin Valley	2,300	² 1931-60	² 1973-75	67	105	—
5. Middle River at Argyle	686	1951-68	1968-70	25	45	—
6. Little Fork River at Little Fork	4,480	1962-68	² 1973-75	161	81	—
7. Crow Wing River at Nimrod ¹	2,620	1940-68	1968-70	14	9	24
8. Yellow Bank River near Odessa ¹	1,030	1940-68	1974-75	25	53	164
9. Chippewa River near Milan	4,840	1938-68	1973-75	56	121	—
10. Redwood River at Marshall ¹	795	1941-68	1968-71	214	420	1,367
11. Redwood River near Redwood Falls ¹	1,800	1936-68	1968-70	88	185	332
12. Cottonwood River near New Ulm ¹	3,320	1936-68	1968-75	190	280	1,130
13. Minnesota River at Mankato ¹	38,600	1960-68	1968-75	140	242	578
14. Zumbro River at Zumbro Falls ¹	2,930	1931-60	² 1973-75	242	168	715
15. Root River near Lanesboro ¹	1,590	1941-68	1968-71	1,084	622	2,848
16. Root River near Houston ¹	3,290	1962-68	³ 1968-75	1,035	594	2,905
17. Cedar River near Austin	1,100	1945-68	² 1973-75	123	89	—
18. West Fork Des Moines at Jackson ¹	3,160	1936-68	³ 1968-75	70	96	363
19. Whetstone River, Big Stone City, SD ¹	1,010	1932-68	1973-75	21	56	201
20. St. Louis River at Forbes ¹	1,940	1964-75	1968-70	88	33	101
21. Straight River at Faribault ¹	1,140	1966-75	1968-71	470	231	196
22. North Fork Whitewater near Elba ¹	262	1967-75	1968-75	572	371	—
23. Minnesota River near New Ulm ¹	24,700	1968-76	1968-75	63	121	470

¹ Station data also used in monthly distribution analysis. ² Additional data for nonconsecutive years also used. ³ Data not taken in 1972. ⁴ Estimated for stations with sufficient data.

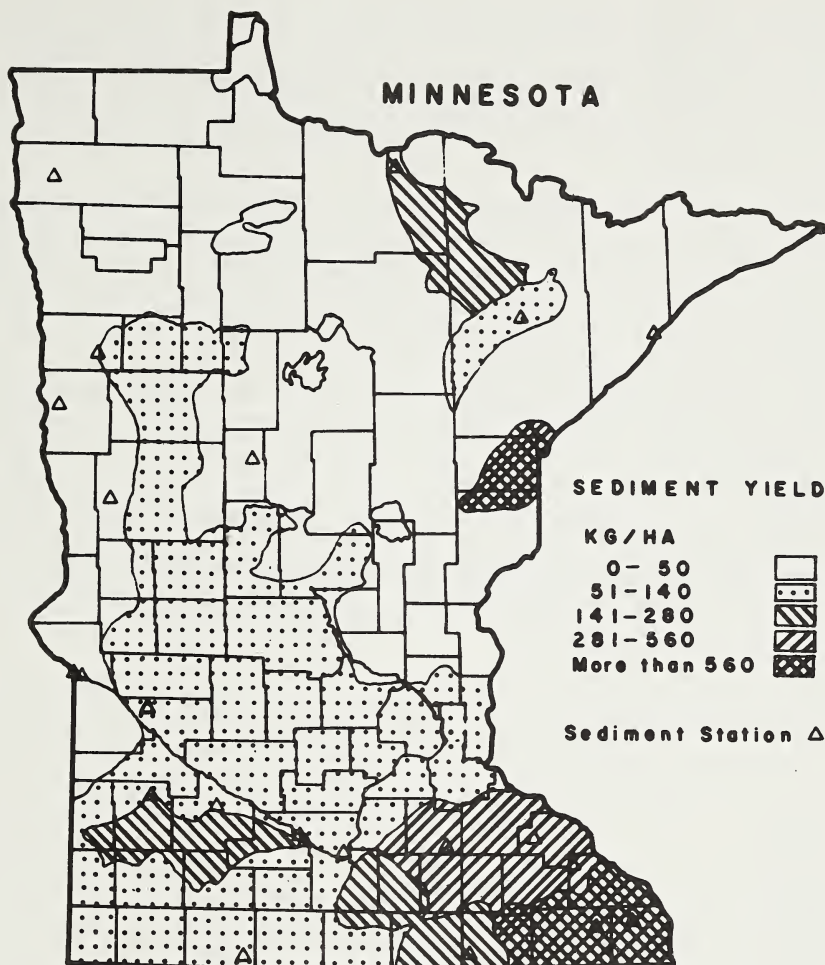


FIGURE 1.—Estimate of average annual sediment yield.

The rivers of the Red River Valley carry little sediment, but the topography, soils, and cropping practices in the southern part of the State cause heavier sediment loads. The southeastern part of the State has the highest yields, exceeding 1,050 kg/ha/yr.

Monthly Distribution of Flow and Sediment-Yield Data

The frequency of the USGS sampling varied from daily or more frequent sampling during periods of high flow to sampling once in several months. For many of the stations, the sampling distribution over the year permitted estimates of monthly averages.

Minnesota climatological data were used to estimate monthly distribution of precipitation (10). In the estimate, we assumed that although the actual amount of pre-

cipitation varies over the State, the percentage of the annual precipitation in any given month remains fairly constant. Data collected from the nine climatological regions in the State support the assumption that the monthly precipitation distributions could be applied on a statewide basis. Monthly distributions were estimated from both long-term records and from records collected during the 8 years that sediment data were collected.

Figure 2 shows that precipitation is lowest in February and gradually increases until it peaks during June. After June, precipitation decreases throughout the rest of the year. The distribution of precipitation during the 8 years of record generally followed the long-term trends, except summers seemed to be slightly drier and Octobers seemed to be unusually wet. Total precipitation during the 8 years of sediment records was about 5 percent above normal.

The monthly distributions of flow, sediment yield, and sediment concentration were based on USGS data. In these analyses, samples taken within a month were averaged and expressed as a percentage of the yearly values, which were obtained by summing the monthly averages. Fifty-eight station-years of data from 16 stations that were fairly well distributed over the State were used to estimate the monthly distributions. The monthly percentages of the annual values were assumed to remain constant over the State. Although we used 58 station-years data, the original data actually covered only 8 physical years, and monthly anomalies may have occurred because of the short record period.

Figure 3 shows distribution of annual flow. The flow remains relatively constant from August through February. In March, the flow increases sharply until it peaks in

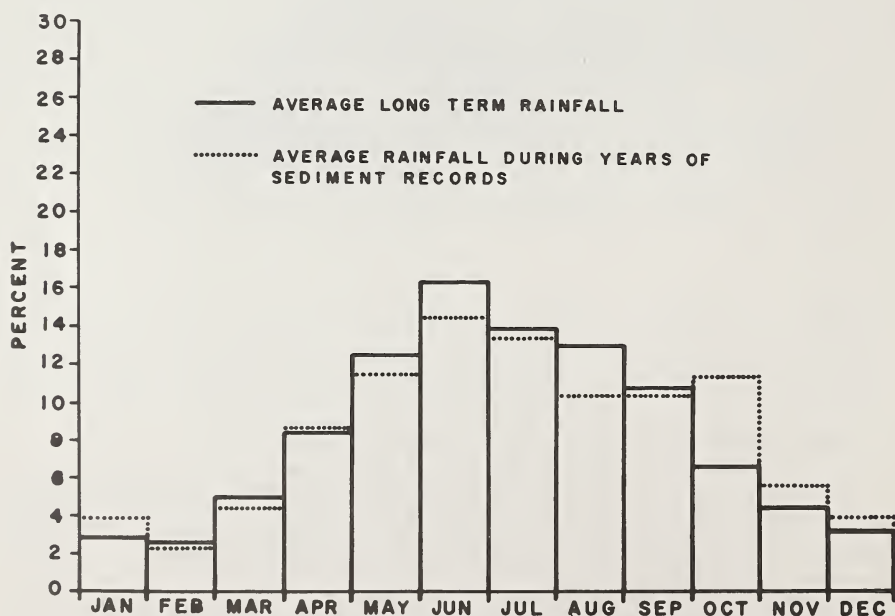


FIGURE 2.—Average percent of annual rainfall by month.

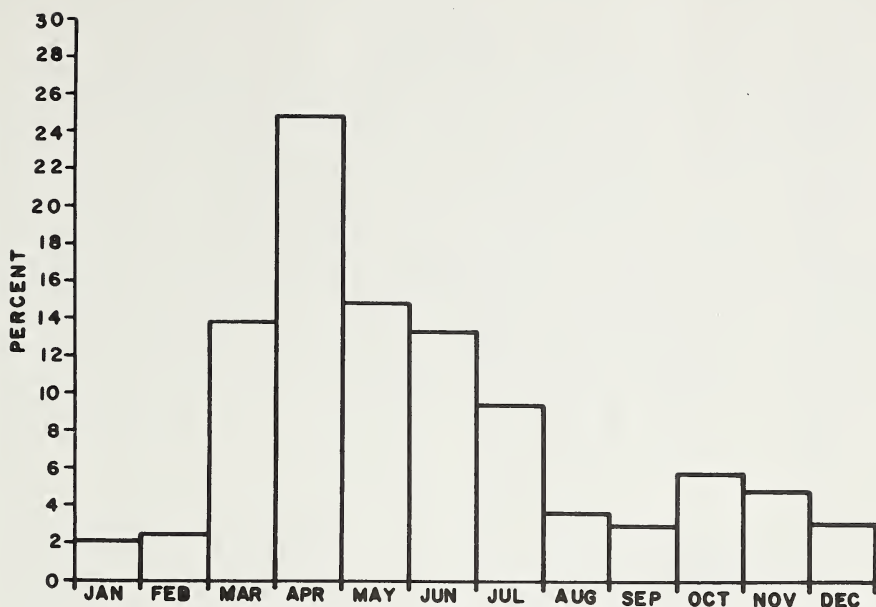


FIGURE 3.—Average percent of annual flow by month.

April. The flow decreased in May and throughout the rest of the summer. The small peak in October probably was caused by several high October rainfalls during the 8 years of record (fig. 2). The average percent of annual flow is highest in April, but the precipitation (fig. 2) peaks during June. The earlier peak in flow is caused by snowmelt.

Comparison of figures 2 and 4 indicates that the April sediment-yield peak does not coincide with the rainfall peak. The sediment-yield graph more closely coincides with that of flow (fig. 3). Although the erosion process is associated with rainfall, the sediment must move by some sediment-transport process in both overland and channel segments to appear as sediment yield. This transport process is demonstrated by the sediment-yield graph, coinciding with that of flow. There also may be stream-bank erosion and channel cleanout taking place with the high flows.

Sediment yield decreases during May. Our short period of sediment records make us question whether the sediment-yield trend actually changes or whether the dip is associated with the particular 8 years of data. Sediment yield is relatively high during June. The June increase could be due to erosive thunderstorms that are common in the area. The slight increase in yield after September could be due to the above normal October rainfall during the 8 years of record.

The average monthly concentrations are shown in figure 5. Concentration is related to flow and yield; hence, the results presented in figure 5 are related to the results presented in figures 3 and 4. The data indicated considerable variation in average concentrations of March, April, May, June, and July and tended to follow the high flow and high sediment-yield cycles indicated in figures 3 and 4. The slight

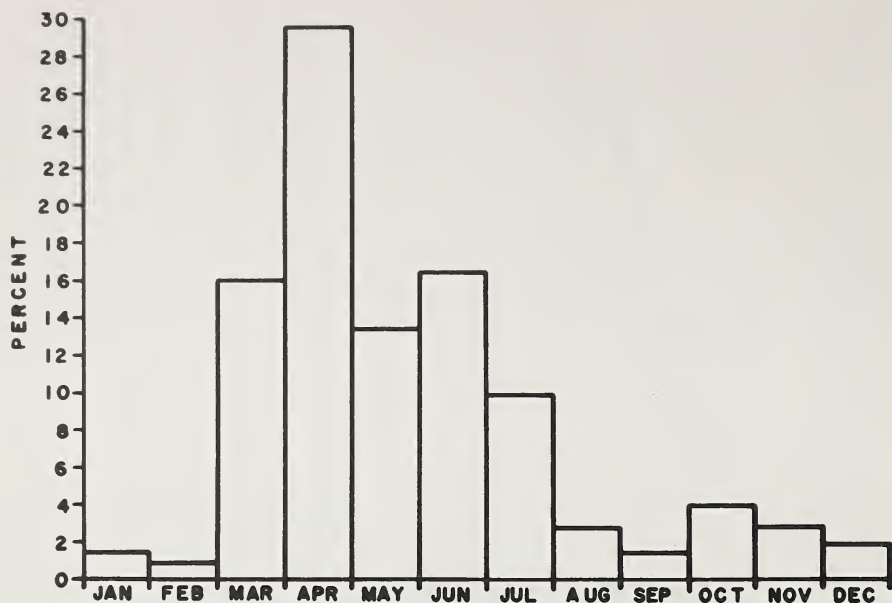


FIGURE 4.—Average percent of annual sediment yield by month.

break in the trend during May could have been due in part to the decrease in sediment yield during that month.

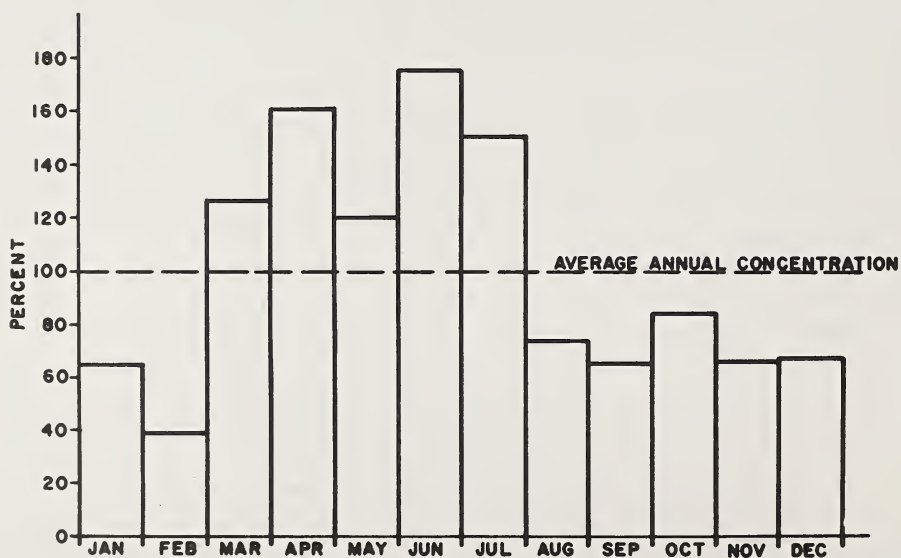


FIGURE 5.—Percent of average annual sediment concentration by month.

Summary

The results presented in this report demonstrate several aspects of sediment yield. Average annual sediment yields were predicted for 23 river basins in Minnesota. The yields, ranging from 10 to 1,084 kg/ha/yr, were predicted on the basis of sediment-rating curves and flow-duration curves. The average basin yields, as well as such parameters as land use, soils, basin size, and geomorphology, were used to divide the State into various sediment-yield categories. Monthly distributions of precipitation, flow, sediment yield, and sediment concentration also were derived. The distributions derived from the USGS data were averaged over 58 station years of data. The number of stations and the amount of data available for the analyses were limited so that only rather general classifications of the State can be made; however, the results indicate the magnitude and variation in sediment yield, flow, and concentrations.

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